ILLUMINATION OPTICAL SYSTEM AND
EXPOSURE APPARATUS HAVING THE SAME

FIELD OF THE INVENTION AND RELATED ART

5   This invention relates to an illumination
optical system and, more particularly, to an
illumination optical system suitably usable in an
exposure apparatus for manufacture of semiconductor
devices.

10   The procedure of mass production of fine
semiconductor devices or liquid crystal flat panels
includes a lithography process. In this process, a
circuit original (mask) is illuminated by an
illumination optical system and with light from a
15   light source such as a Hg lamp, and, by using a high
resolution projection optical system, a circuit
pattern of the original is transferred and printed on
a photosensitive substrate (wafer). Exposure
apparatuses used in such lithographic process may be
20   generally classified into a stepper (sequential
exposure method) wherein exposure and stepwise motion
of a substrate are repeated (the exposure being made
while the wafer is held stationary) and a scanner
wherein an original and a substrate are moved in
25   synchronism with each other, in repetition.
Particularly, for mass production of liquid crystal
flat panels, whole-exposure type unit-magnification

scanning exposure apparatuses are used.

Figure 1 illustrates such whole-exposure type
scanning exposure apparatus for use in manufacture of
liquid crystal flat panels. In the apparatus of

5 Figure 1, an ultra-high pressure Hg lamp 101 is used
as a light source which emits, as main spectrum, light
of i-line (365 nm), h-line (405 nm) or g-line (436
nm). The light from the light source is once
collected by an elliptical mirror 102 upon a light

10 entrance surface of a light integrator 103. The light
integrator 103 specifically comprises a fly's eye lens
having a plurality of convex lenses. Ultraviolet
light beams emitted from the light integrator 103 are
once projected by a collimator 104 onto a plane 105 to

15 be illuminated. Disposed on this plane 105 is a slit
plate having an opening of arcuate shape such as shown
in Figure 2, for restricting the illumination range.
Imaging optical system 106 serves to image the arcuate
slit plate (as object plane) so that an illumination

20 region of arcuate shape is defined on a mask 107.
This is the structure of an illumination optical
system.

The mask 107 has a circuit pattern formed
thereon by using metal such as chromium. Light from

25 this surface of the mask (as object plane) then enters
a unit-magnification and mirror whole-projection
exposure optical system 115. This projection optical

system 115 basically comprises two mirrors of a concave surface mirror 111 and a convex surface mirror 112. Flat mirrors 110 and 113 function to deflect the light path, so that a mask 107 and a glass plate

5 (wafer) 114 having a coating of photosensitive resist can be scanned in synchronism with each other in the same direction (the direction of arrows in the drawing). Light emitted from a single point on the mask 107 is reflected by mirrors 110, 111, 112, 111

10 and 113, in this order, and it is collected upon the plate 114. Then, by using a portion of a good-image region of arcuate shape (the above-described illumination region) which is revolutionally symmetric with respect to the optical axis O-O' of the

15 projection system 115, the circuit pattern of the mask 7 is transferred to the plate.

In the apparatus shown in Figure 1, however, since an arcuate range 108 is extracted from the illumination region 109 (of square or rectangular

20 shape) of the fly's eye lens as shown in Figure 2, the illumination efficiency is undesirably low.

Japanese Published Patent Application, Publication No. 068846/1993 shows an optical system wherein an optical fiber is used to directly define an

25 arcuate illumination region. Figure 3 shows such an optical system. Light from a Hg lamp 201 is collected by a condenser lens 210 onto the light entrance

surfaces of a fiber bundle 204. The light entrance surfaces of the fiber bundle 204 have a circular or rectangular (square) shape, and the light exit surfaces of the bundle are bound into a arcuate shape

5 to meet a projection optical system. Denoted at 205 is a condensing optical system, wherein an arcuate imaging plane 206 corresponds to the illumination surface 105 or the mask 107 in Figure 1. Since, however, in the optical system of Figure 3, only a

10 portion of the light from the lamp corresponding to the opening face of the condenser lens 210 can be caught, the illumination efficiency is very low.

Figure 4 shows another optical system also disclosed in Japanese Published Patent Application,

15 Publication No. 068846/1993. In this case, the light emission point of a lamp 301 is disposed at a first focal point of an elliptical mirror 302, so that the light can be caught by the mirror 302 without loss. The light is directed to a fiber bundle 304 having its

20 light entrance surface disposed at a plane containing the second focal point (second focal plane 303). After it, like the optical system of Figure 3, the fiber bundle 304 defines an arcuate illumination region, and efficient illumination is provided.

25 However, even in apparently efficient arrangement of Figure 4, there are serious inconveniences such as below.

Figure 5 illustrates light emission distribution of an ultra-high pressure Hg lamp. When a plane PL extending through the light emission point of a lamp and being perpendicular to the lengthwise

5   direction of the lamp is put and also an increasing angle NA is put in a direction away from the plane PL, as shown in Figure 5, the luminous intensity distribution has a doughnut-like shape (with swells in lateral directions in the drawing) being

10   revolutionally symmetrical with respect to an axis along the lengthwise direction of the lamp. More specifically, the light emission intensity is highest upon the plane PL and it decreases with enlargement of the angle NA. If such a lamp is combined with an

15   elliptical mirror as shown in Figure 4, the resultant luminous intensity distribution characteristic of light as collected at the second focal point is such as shown by a solid line in Figure 6 that there is a central void (the distributed light intensity is close

20   to zero in the vicinity of the angle NA of zero), this being attributable also to the void in structure of the elliptical mirror 302.

On the other hand, an ultraviolet ray fiber capable of efficiently transmitting a wavelength not

25   longer than 400 nm comprises a central core made of quartz glass and a peripheral crud of mixture of quartz glass with a small amount of impurities,

causing a small decrease of refractive index. Through total reflection inside the fiber, the light is transmitted from the light entrance end to the light exit end. The material for producing such ultraviolet ray fiber is currently limited only to quartz and, for this reason, the numerical aperture of the fiber (i.e., largest distribution angle transmissible with respect to the optical axis of the fiber) may be 0.2 to 0.25, at the best. Broken line in Figure 6 depicts luminous intensity distribution of light as received by the fiber, such as above.

In the optical system of Figure 4, therefore, the total light quantity which can be practically transmitted through the fiber corresponds to the integrated value, with respect to the angle NA, of multiplication of the two curves in Figure 6. The quantity of light passing through the fiber is thus attenuated largely and, therefore, the illumination efficiency is still low.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an illumination optical system by which, in a system having a total reflection type light transmitting element, a high illumination efficiency can be attained.

In accordance with an aspect of the present

invention, there is provided an illumination optical system, comprising: a luminous intensity distribution converting optical system for converting an illuminance distribution of a light source image into

5   a luminous intensity distribution upon a predetermined plane; a total reflection type light transmitting element having its light entrance surface disposed substantially in coincidence with the predetermined plane; and a light collecting optical system for

10   defining an illumination region upon a surface to be illuminated, by use of light from said light transmitting element.

In accordance with another aspect of the present invention, there is provided an illumination

15   optical system, comprising: a luminous intensity distribution converting optical system for converting an illuminance distribution of a light source image into a luminous intensity distribution upon a predetermined plane; an optical fiber bundle having

20   its light entrance surface disposed substantially in coincidence with the predetermined plane; and a light collecting optical system for defining an illumination region upon a surface to be illuminated, by use of light from said optical fiber bundle.

25   In accordance with a further aspect of the present invention, there is provided an illumination optical system, comprising: a luminous intensity

distribution converting optical system for converting
a luminous intensity distribution of plural light
fluxes having different incidence angles into an
illuminance distribution upon a predetermined plane; a

5   total reflection type light transmitting element
having its light entrance surface disposed
substantially in coincidence with the predetermined
plane; and a light collecting optical system for
defining an illumination region upon a surface to be

10   illuminated, by use of light from said light
transmitting element.

In accordance with a yet further aspect of
the present invention, there is provided an exposure
apparatus, comprising: an illumination optical system

15   as recited above; and a projection optical system for
transferring, by exposure, a pattern of a mask as
illuminated with said illumination optical system,
onto a wafer.

In accordance with a still further aspect of

20   the present invention, there is provided a device
manufacturing method, comprising the steps of:
applying a resist to a wafer; transferring, by
exposure, a pattern of a mask onto the wafer by use of
an exposure apparatus as recited above; and developing

25   the wafer having the pattern transferred thereto.

These and other objects, features and
advantages of the present invention will become more

apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic view of an example of whole-exposure type scanning exposure apparatus.

Figure 2 is a schematic view for explaining an illumination region. in the apparatus of Figure 1.

Figures 3 and 4 are schematic view, respectively, showing examples of illumination optical system having a fiber bundle.

Figure 5 is a schematic view for explaining luminous intensity distribution of an ultra-high pressure Hg lamp.

Figure 6 is a schematic view for explaining incidence luminous intensity distribution of light upon a fiber bundle.

Figure 7 is a schematic view of a general structure of an illumination optical system according to a first embodiment of the present invention.

Figure 8 is a schematic view for explaining details of a luminous intensity distribution converting optical system, in the first embodiment of the present invention.

Figure 9 is a schematic view for explaining

incidence luminous intensity distribution upon a fiber bundle, in the first embodiment of the present invention.

Figure 10 is a schematic view of a general structure of a luminous intensity distribution converting optical system, in a second embodiment of the present invention.

Figure 11 is a schematic view for explaining incidence luminous intensity distribution upon a fiber bundle, in the second embodiment of the present invention.

Figure 12 is a schematic view of a general structure of an illumination optical system according to a third embodiment of the present invention.

Figure 13 is a schematic view of a general structure of an illumination optical system according to a fourth embodiment of the present invention.

Figure 14 is a schematic view of for explaining a general structure of a luminous intensity distribution converting optical element, in a fifth embodiment of the present invention.

Figure 15 is a schematic view of a general structure of an exposure apparatus according to a sixth embodiment of the present invention.

Figure 16 is a flow chart of semiconductor device manufacturing processes.

Figure 17 is a flow chart for explaining

details of a wafer process, in the procedure of Figure 16.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[First Embodiment]

Figure 7 is a schematic view of a general structure of an illumination optical system according to a first embodiment of the present invention. Figure 8 is a schematic view for explaining details of a luminous intensity distribution converting optical system of the illumination optical system of Figure 7.

In Figure 7, Hg lamp 1 has a light emission point which is disposed at one focal point (first focal point) of an elliptical mirror 2. Light emitted from the lamp 1 is collected by the influence of the mirror at another focal point (second focal point) of the mirror. The elliptical mirror 2 has another opening at its back, for replacement of an electrode of the lamp 1. Even if there is no such opening, because of the luminous intensity distribution characteristic of the lamp itself, substantially no light comes to the opening area at the back. Thus, at the second focal point plane 8, an illuminance distribution of Gaussian distribution shape (a distribution wherein the intensity (illuminance) is higher at a portion adjacent to the optical axis, than the intensity at a peripheral portion), due to the

aberration of the mirror 2. Therefore, in terms of luminous intensity distribution, light having a distribution with central void (a distribution wherein the intensity is large in a direction perpendicular to the optical axis, as compared with the intensity along the optical axis direction) is collected. The largest level of the luminous intensity distribution is determined by the opening diameter of the elliptical mirror 2.

Disposed adjacent to the second focal plane 3 is a luminous intensity distribution converting optical system 12, according to an important feature of the present invention. The converting optical system 12 comprises two lens units of a field lens 10 and a collimator lens 11. As shown in Figure 8, these lens units have the same focal length f, with their principal points being spaced by the length f. This arrangement satisfies what can be called a Fourier transform relation, and a illuminance distribution upon an entrance pupil of the field lens 10 (i.e., upon the second focal plane 3) is converted into a luminous intensity distribution upon an exit pupil of the collimator lens 11 (i.e., upon the light entrance surface 20 of a fiber). Also, oppositely, the luminous intensity distribution (with central void) upon the entrance pupil of the field lens 10 is converted into an illuminance distribution upon the

exit pupil of the collimator lens (the light entrance surface 20 of the fiber). The light beam diameters at these pupil planes are the same, in principle (no beam expansion). Fiber bundle 4 having plural optical

5   fibers bound together, is used for arcuate illumination and, in this embodiment, the exit ends of the fibers are combined into an arcuate shape. By means of a condensing optical system 5 after the fiber bundle, the arcuate shape is imaged upon an imaging

10   plane 6 (the surface to be illuminated). Basically, the fiber bundle does not change the luminous intensity distribution characteristic. Therefore, upon the imaging plane 6, uniform luminous intensity distribution characteristic the same as that when

15   entered the fiber bundle 4 is reproduced.

          In Figure 9, a broken line depicts the reception luminous intensity distribution characteristic of the fiber bundle 4, while a solid line depicts incidence luminous intensity distribution

20   of light impinging on the fiber bundle 4 in accordance with this embodiment. Due to the function of the converting optical system 12, the incidence luminous intensity distribution of light into the fiber bundle 4 has a Gaussian distribution. Therefore, the

25   substantive transmission light quantity of the fiber bundle 4 (the integrated value of the products of solid line and broken line) increases notably as

compared with that of the optical system of Figure 6.
Thus, the utilization efficiency of light emitted from
the lamp 1, i.e., the illumination efficiency, is
improved significantly. In this embodiment, the fiber
5   bundle 4 functions to transform a light beam of
rectangular shape into light beam of arcuate shape, on
the basis of the shapes of its entrance end and its
exit end. However, even if the entrance end and exit
end have the same shape, the advantageous effects of
10   this embodiment are attainable.

[Second Embodiment]

This embodiment uses a converting optical
system different from that of the first embodiment.
15   Except for this, the structure is the same as that of
the first embodiment. Figure 10 is a schematic view
of a general structure of a luminous intensity
distribution converting optical system of this
embodiment. This embodiment uses an optical rod 21,
20   in place of the field lens 10 of Figure 7. The
optical rod 21 has a light entrance face which is
disposed adjacent to the second focal plane 3 of the
elliptical mirror 2. The light exit face of it is
disposed at a front focal point plane 17 of the
25   collimator lens 11. With this arrangement, even if
there is an illuminance distribution of Gaussian shape
at the light entrance face of the rod 21, a flat

illuminance distribution can be produced at the light exit face of the rod 21 due to the uniforming effect of the rod (the degree of flatness is adjustable by the length of the rod). Therefore, the incidence

5   luminous intensity distribution of light into the fiber bundle 4 can be flattened.

In Figure 11, a solid line depicts an incidence luminous intensity distribution being flat, as can be provided by this embodiment. Like the case

10   of Figure 9, by multiplying it with the reception luminous intensity distribution characteristic (broken line) of the fiber 4, the substantive transmission light quantity of the fiber bundle 4 is increased notably, and the illumination efficiency is improved

15   significantly.

[Third Embodiment]

Figure 12 is a schematic view of a general structure of an illumination optical system according

20   to a third embodiment of the present invention. This embodiment differs from the first embodiment of Figure 7 in that an optical rod 22 is inserted between the luminous intensity distribution converting optical system 12 and the fiber bundle 4.

25   In the first embodiment, since the illuminance distribution upon the light entrance surface 20 of the fiber has a central void, there may

occur non-uniformness of illuminance at the light exit
end. Such non-uniformness of illuminance may cause
non-uniformness of illuminance upon the imaging plane
6. Therefore, when the illumination optical system of

5   Figure 7 is used in an exposure apparatus, the
linewidth of a circuit pattern to be finally printed
may become uneven, which may degrade precision of
exposure. This may be avoided if the fibers are bound
together at random. This embodiment however

10   positively avoids it. In accordance with this
embodiment, due to the function of the optical rod 22,
light of uniform illuminance distribution can be
transmitted to the fiber bundle, such that the non-
uniformness of illuminance upon the imaging plane 6

15   can be decreased significantly.

While the converting optical system 12 of
this embodiment has the same structure as of the first
embodiment, it may have the same structure as of the
luminous intensity distribution converting optical

20   system of the second embodiment shown in Figure 10.

[Fourth Embodiment]

Figure 13 is a schematic view of a general
structure of an illumination optical system according

25   to a fourth embodiment of the present invention.
While the preceding embodiments use a combination of
Hg lamp (as light source) and elliptical mirror, this

embodiment uses two lasers 40 and 41 as light source and an optical system for directing light beams supplied from these lasers to an optical rod in oblique incidence. The luminous intensity

5   distribution converting optical system of the first embodiment may be used as this directing optical system.

An optical rod is an optical element for transmitting light through total reflection. However,

10 if the NA of light entering it is too large, all the light is not totally reflected and a portion of the light leaks out of the side face of the rod. In order to prevent this, the luminous intensity distribution converting optical system 12 is disposed at the

15 entrance side of the rod 42, such that the NA of the light impinging on the rod 42 is converted toward the center. In the case of this embodiment, even if the distance between the field lens 10 and the collimator lens 11, constituting the luminous intensity

20 distribution converting optical system 12, deviates from their focal lengths to some extent, it can be accepted unless it is within a range wherein the incident light can be transmitted by the rod on the basis of total reflection.

25

[Fifth Embodiment]

This embodiment uses a luminous intensity

distribution converting optical system different from
that of the first embodiment. Except for this, the
structure is the same as that of the first embodiment.
Figure 14 is a schematic view of a general structure
of a luminous intensity distribution converting
optical system according to this embodiment.

The luminous intensity distribution
converting optical system of this embodiment differs
from that of the first embodiment in that a fly's eye
lens 31 of known structure is disposed at the second
focal point position 3 of the elliptical mirror 2.
The fly's eye lens 31 has its light exit surface
disposed at a front focal point plane of a condenser
lens 32, placed after the lens. Also, the fiber
entrance surface 20 is disposed at the rear focal
point plane of the condenser lens 32. With this
structure, upon the second focal plane 3 and the fiber
entrance surface 20, there are produced an illuminance
distribution and a luminous intensity distribution
such as shown in Figure 14. More specifically, an
illuminance distribution a of Gaussian shape as
defined at the light entrance surface of the fly's eye
lens 31 (i.e., at the second focal point plane 3) is
converted into a uniform distribution b upon the fiber
entrance surface 20, due to the function of the fly's
eye lens 31. Simultaneously, a luminous intensity
distribution c of a shape with central void as

produced at the light entrance surface of the fly's
eye lens 31 (the second focal point 3) is transformed
into a Gaussian distribution b upon the fiber entrance
surface 20. Thus, the present invention functions
5   well.

[Sixth Embodiment]

Figure 15 is a schematic view for explaining
a sixth embodiment of the present invention. This
10 embodiment is directed to a system in which an
illumination optical system according to any one of
the first to fifth embodiments is incorporated into an
exposure apparatus for manufacture of semiconductor
devices. In Figure 15, denoted at 30 is an
15 illumination optical system such as described above.
It functions to illuminate a mask 31 uniformly, which
is placed at an imaging plane 6 or a plane optically
conjugate therewith. Denoted at 32 is a projection
optical system for lithographically transferring a
20 circuit pattern, formed on the mask 31, onto a wafer
32 which is coated with a resist.

In this embodiment, the projection optical
system 32 may comprise a unit magnification type
mirror scanning optical system such as shown in Figure
25 1, or it may comprise a stepper reduction projection
lens. Alternatively, this embodiment may be applied
to an illumination optical system for a reduction type

step-and-scan exposure apparatus (scanner).

When an illumination optical system according to the present invention is incorporated into an exposure apparatus such as described above, the

5 following advantageous effects are obtainable. The luminous intensity distribution of illumination light such as shown in Figure 9 is emitted from the illumination optical system while the distribution being preserved, and it illuminates the mask 31

10 surface. Then, the light passes through the mask 31 surface (while a portion of the light is transformed into diffractive light), and it reaches the pupil plane 33 of the projection optical system 32. Upon this pupil plane 33, there is produced an illuminance

15 distribution directly corresponding to the luminous intensity distribution at the mask 31 surface. Usually, this distribution is called an effective light source, and it is well known that the shape of this effective light source largely affects the

20 resolution performance in pattern printing. If the distribution has a Gaussian shape (small sigma) wherein the light intensity is large at a portion close to the optical axis (NA = 0) of the projection optical system 32, there is a tendency that, depending

25 on the pattern, the resolution depth is expanded. Of course, the effect of high illumination efficiency through the illumination optical system 30 is held.

In the embodiments described above, the wavelength of illumination light to be used comprises a wavelength of about 350 - 450 nm, as of i-line, h-line or g-line. Also, the glass material for the

5   fiber may comprise a quartz material having high transmission factor to such wavelength. However, the present invention is not limited to what described above. Light of longer wavelength such as visible light or infrared rays may be used, and the fiber may

10   be made of a multiple-component glass material. In such occasion, the transmission characteristic of the fiber is not limited to the total reflection type. A distributed refractivity type may be used, though there may be a similar problem like the case of total

15   reflection type fiber. This is because it has no difference over the total reflection type fiber in that there is a limit in respect to the transmission luminous intensity distribution angle. Further, the same applies to deep ultraviolet light of a wavelength

20   not longer than 200 nm.

[Seventh Embodiment]

Next, an embodiment of a semiconductor device manufacturing method which uses an exposure apparatus

25   according to the sixth embodiment, will be explained.

Figure 16 is a flow chart of procedure for manufacture of microdevices such as semiconductor

chips (e.g. ICs or LSIs), liquid crystal panels, or
CCDs, for example.

Step 1 is a design process for designing a
circuit of a semiconductor device. Step 2 is a
process for making a mask on the basis of the circuit
pattern design. Step 3 is a process for preparing a
wafer by using a material such as silicon. Step 4 is
a wafer process which is called a pre-process wherein,
by using the so prepared mask and wafer, circuits are
practically formed on the wafer through lithography.
Step 5 subsequent to this is an assembling step which
is called a post-process wherein the wafer having been
processed by step 4 is formed into semiconductor
chips. This step includes assembling (dicing and
bonding) process and packaging (chip sealing) process.
Step 6 is an inspection step wherein operation check,
durability check and so on for the semiconductor
devices provided by step 5, are carried out. With
these processes, semiconductor devices are completed
and they are shipped (step 7).

Figure 17 is a flow chart showing details of
the wafer process.

Step 11 is an oxidation process for oxidizing
the surface of a wafer. Step 12 is a CVD process for
forming an insulating film on the wafer surface. Step
13 is an electrode forming process for forming
electrodes upon the wafer by vapor deposition. Step

14 is an ion implanting process for implanting ions to the wafer. Step 15 is a resist process for applying a resist (photosensitive material) to the wafer. Step 16 is an exposure process for printing, by exposure, the circuit pattern of the mask on the wafer through the exposure apparatus described above. Step 17 is a developing process for developing the exposed wafer. Step 18 is an etching process for removing portions other than the developed resist image. Step 19 is a resist separation process for separating the resist material remaining on the wafer after being subjected to the etching process. By repeating these processes, circuit patterns are superposedly formed on the wafer.

With these processes, high density microdevices can be manufactured.

While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.